TRANSVERSE Λ POLARIZATION IN UNPOLARIZED SEMI-INCLUSIVE DIS [*]

M. ANSELMINO[a], D. BOER[b], U. D'ALESIO[c], F. MURGIA[c]

[a]*Dipartimento di Fisica Teorica, Università di Torino, and INFN, Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy*

[b]*RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA*

[c]*INFN, Sezione di Cagliari, and Dipartimento di Fisica, Università di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy*

The long-standing problem of transverse Λ polarization in high-energy collisions of unpolarized hadrons can be tackled by considering new, spin and $\boldsymbol{k}_\perp$-dependent quark fragmentation functions for an unpolarized quark into a polarized, spin-1/2 hadron. Simple phenomenological parameterizations of these new "polarizing fragmentation functions", which describe quite well the experimental data on Λ and $\bar{\Lambda}$ hyperons produced in $p-A$ processes, are utilized and extended here to give predictions for transverse Λ polarization in semi-inclusive DIS.

1 Transverse Λ polarization in hadronic collisions

Transverse hyperon polarization in high-energy, unpolarized hadron collisions is a long-standing challenge for theoretical models of hadronic reactions. We have recently proposed an approach [1] to this problem based on perturbative QCD and its factorization theorems, and including polarization and intrinsic transverse momentum, $\boldsymbol{k}_\perp$, effects. This approach was already applied to the study of transverse single spin asymmetries in inclusive particle production at large $x_{_F}$ and medium-large $p_{_T}$. [2] It requires the introduction of a new class of leading-twist, polarized and $\boldsymbol{k}_\perp$-dependent distributions and fragmentation functions (FF). These new functions can be extracted by fitting available experimental data and consistently applied to give predictions for other processes.

A large amount of data on transverse Λ polarization, $P_{_T}^\Lambda$, in unpolarized hadronic collisions is available; the main properties of experimental data at $x_{_F} \gtrsim 0.2$ can be summarized as follows: 1) $P_{_T}^\Lambda < 0$; 2) Starting from zero at very low $p_{_T}$, $|P_{_T}^\Lambda|$ increases up to $p_{_T} \sim 1$ GeV, where it flattens to an almost constant value, up to the highest measured $p_{_T}$ of about 3 GeV; 3) The value of $|P_{_T}^\Lambda|$ in this plateau regime increases almost linearly with $x_{_F}$; 4) $P_{_T}^{\bar{\Lambda}}$ is compatible with zero. In our approach, the transverse hyperon polarization in unpolarized hadronic reactions at large $p_{_T}$ can be written, e.g. for the $pp \to \Lambda^\uparrow X$ case , as follows [1]

[*]Talk delivered by F. Murgia at the IX International Workshop on Deep Inelastic Scattering (DIS2001), Bologna, 27 April - 1 May 2001.

$$P_T^\Lambda(x_F, p_T) = \frac{d\sigma^{pp\to\Lambda^\uparrow X} - d\sigma^{pp\to\Lambda^\downarrow X}}{d\sigma^{pp\to\Lambda^\uparrow X} + d\sigma^{pp\to\Lambda^\downarrow X}} \tag{1}$$

$$= \frac{\sum \int dx_a\, dx_b \int d^2\boldsymbol{k}_{\perp c}\, f_{a/p}(x_a)\, f_{b/p}(x_b)\, d\hat\sigma(x_a, x_b; \boldsymbol{k}_{\perp c})\, \Delta^N D_{\Lambda^\uparrow/c}(z, \boldsymbol{k}_{\perp c})}{\sum \int dx_a\, dx_b \int d^2\boldsymbol{k}_{\perp c}\, f_{a/p}(x_a)\, f_{b/p}(x_b)\, d\hat\sigma(x_a, x_b; \boldsymbol{k}_{\perp c})\, D_{\Lambda/c}(z, \boldsymbol{k}_{\perp c})},$$

where $d\sigma^{pp\to\Lambda X}$ stands for $E_\Lambda d\sigma^{pp\to\Lambda X}/d^3\boldsymbol{p}_\Lambda$; $f_{a/p}(x_a)$ are the usual unpolarized parton densities; $d\hat\sigma(x_a, x_b; \boldsymbol{k}_{\perp c})$ is the lowest order partonic cross section with the inclusion of $\boldsymbol{k}_{\perp c}$ effects; $D_{\Lambda/c}(z, \boldsymbol{k}_{\perp c})$ and $\Delta^N D_{\Lambda^\uparrow/c}(z, \boldsymbol{k}_{\perp c})$ are respectively the unpolarized and the *polarizing* FF [1,3] for the process $c \to \Lambda + X$.

Eq. (1) is based on some simplifying conditions: 1) As suggested by experimental data, the Λ polarization is assumed to be generated in the fragmentation process; 2) Λ FF include also Λ's coming from decays of other hyperon resonances. In order to reduce the number of parameters, as a first step the full integration over $\boldsymbol{k}_{\perp c}$ is replaced by evaluation at an *effective*, average $\langle k_\perp^0(z)\rangle$; $\langle k_\perp^0(z)\rangle$ and $\Delta^N D_{\Lambda^\uparrow/c}(z, \langle k_\perp^0\rangle)$ are then parameterized by using simple expressions of the form $N z^a (1-z)^b$. We impose appropriate positivity bounds on $\Delta^N D_{\Lambda^\uparrow/c}$ and consider only leading (or valence, q_v) quarks in the fragmentation process. In this way, a very good fit to experimental data for Λ and $\bar\Lambda$ polarization, at $p_T \gtrsim 1$ GeV, can be obtained. [1] Moreover, it results that $\Delta^N D_{\Lambda^\uparrow/u,d} < 0$, $\Delta^N D_{\Lambda^\uparrow/s} > 0$, and $\Delta^N D_{\Lambda^\uparrow/s} > |\Delta^N D_{\Lambda^\uparrow/u,d}|$. Notice that these general features are similar to those expected for the longitudinally polarized FF, $\Delta D_{\Lambda/q}(z)$, in the well-known Burkardt-Jaffe model. [4]

2 P_T^Λ and $P_T^{\bar\Lambda}$ in semi-inclusive DIS at $x_F > 0$

We want now to extend our analysis to the case of Λ polarization in unpolarized semi-inclusive DIS (SIDIS), $\ell p \to \ell' \Lambda^\uparrow X$. We neglect the intrinsic $\boldsymbol{k}_\perp$ effects in the unpolarized initial proton. Then, at leading twist and leading order, in the virtual boson-proton c.m. reference frame the virtual boson-quark scattering is collinear, and the intrinsic transverse momentum of the Λ with respect to the fragmenting quark and its observed transverse momentum $\boldsymbol{p}_T$ coincide. To study $P_T^\Lambda(x_F, p_T)$ in the SIDIS case we then need the full $\boldsymbol{k}_\perp$ dependence of the polarizing FF. To this end we consider a simple gaussian parameterization, defining

$$D_{\Lambda/q}(z, k_\perp) = \frac{d(z)}{M^2}\, \exp\Big[-\frac{k_\perp^{\,2}}{M^2 f(z)}\Big], \tag{2}$$

$$\Delta^N D_{\Lambda^\uparrow/q}(z, \boldsymbol{k}_\perp) = \frac{\delta(z)}{M^2}\, \frac{k_\perp}{M}\, \exp\Big[-\frac{k_\perp^{\,2}}{M^2 \varphi(z)}\Big]\, \sin\phi, \tag{3}$$

where ϕ is the azimuthal angle between the Λ intrinsic transverse momentum and the polarization vector. We use the general relations $\int d^2k_\perp D_{\Lambda/q}(z,k_\perp) = D_{\Lambda/q}(z)$, $\int d^2k_\perp\, k_\perp^{\,2}\, D_{\Lambda/q}(z,k_\perp) = \langle k_\perp^{\,2}(z)\rangle\, D_{\Lambda/q}(z)$. By imposing the positivity bound $|\Delta^N D_{\Lambda^\uparrow/q}(z,\boldsymbol{k}_\perp)|\ /\ D_{\Lambda/q}(z,k_\perp) \leq 1\ \forall\, z\,\mathrm{and}\,\boldsymbol{k}_\perp$, and requiring full consistency with the approximations and parameterizations adopted in the fitting procedure to $pp\to\Lambda^\uparrow X$ data [that is, we require that, when appropriately used into Eq. (1), our parameterizations (2), (3) obey the simplifying assumption $\int d^2\boldsymbol{k}_\perp\, F(\boldsymbol{k}_\perp) \Rightarrow F(\langle k_\perp^0\rangle)$], we find:

$$D_{\Lambda/q}(z,k_\perp) = \frac{D_{\Lambda/q}(z)}{\pi\langle k_\perp^{\,2}(z)\rangle}\, \exp\left[-\frac{k_\perp^{\,2}}{\langle k_\perp^{\,2}(z)\rangle}\right], \tag{4}$$

$$\Delta^N D_{\Lambda^\uparrow/q_v}(z,k_\perp) = \Delta^N D_{\Lambda^\uparrow/q_v}(z,\langle k_\perp^0\rangle)\, \frac{4\sqrt{2}}{\sqrt{\pi}}\, \frac{k_\perp}{\langle k_\perp^{\,2}(z)\rangle^{3/2}}\, \exp\left[-2\,\frac{k_\perp^{\,2}}{\langle k_\perp^{\,2}(z)\rangle}\right]. \tag{5}$$

Notice that: 1) The factor 2 of difference in the exponential of $\Delta^N D_{\Lambda^\uparrow/q_v}$ w.r.t. $D_{\Lambda/q}$ is required by consistency with the approach in the $p-A$ case, and is by far more stringent than the most general bounds ; 2) There is a simple relation between our "effective" $k_\perp^0(z)$ and the physical, observable $\langle k_\perp^{\,2}(z)\rangle$ of the Λ inside the fragmenting jet: $\langle k_\perp^{\,2}(z)\rangle = 2\,\langle k_\perp^0(z)\rangle^2$. These relations are a very direct consequence of our approach and can be tested in SIDIS processes.

Finally, the positivity bound reads now

$$\frac{|\Delta^N D_{\Lambda^\uparrow/q_v}(z,\langle k_\perp^0\rangle)|}{D_{\Lambda/q}(z)/2} \leq \frac{\sqrt{e}}{2\sqrt{\pi}} \simeq 0.465\,. \tag{6}$$

This bound is consistently satisfied by the original parameterizations obtained for the $p\,A\to\Lambda^\uparrow X$ case.[1]

Choosing the $\hat{z}$-axis along the virtual boson direction, the $\hat{x}$-axis along the Λ transverse momentum $\boldsymbol{p}_T$, the transverse $\uparrow$ direction results along the positive $\hat{y}$-axis, and $\phi=\pi/2$. In this configuration, P_T^Λ is given, in the $\ell p\to\ell'\Lambda^\uparrow X$ case (HERMES, H1, ZEUS, COMPASS, E665, etc.) with e.m. contributions only, by[3]

$$P_T^\Lambda(x,y,z,p_T) = \frac{\sum_q e_q^2\, f_{q/p}(x)\,[\,d\hat\sigma^{\ell q}/dy\,]\,\Delta^N D_{\Lambda^\uparrow/q}(z,p_T)}{\sum_q e_q^2\, f_{q/p}(x)\,[\,d\hat\sigma^{\ell q}/dy\,]\,D_{\Lambda/q}(z,p_T)}\,. \tag{7}$$

In the case of weak CC processes, $\nu_\mu p\to\mu^-\Lambda^\uparrow X$ (NOMAD, ν-factories, etc.) one finds ($f_{u/p}(x)=u$, etc.)

$$P_T^\Lambda(x,y,z,p_T) = \frac{(d+R\,s)\Delta^N D_{\Lambda^\uparrow/u} + \bar{u}\,(\Delta^N D_{\Lambda^\uparrow/\bar{d}} + R\,\Delta^N D_{\Lambda^\uparrow/\bar{s}})(1-y)^2}{(d+R\,s)D_{\Lambda/u} + \bar{u}\,(D_{\Lambda/\bar{d}} + R\,D_{\Lambda/\bar{s}})(1-y)^2}\,, \tag{8}$$

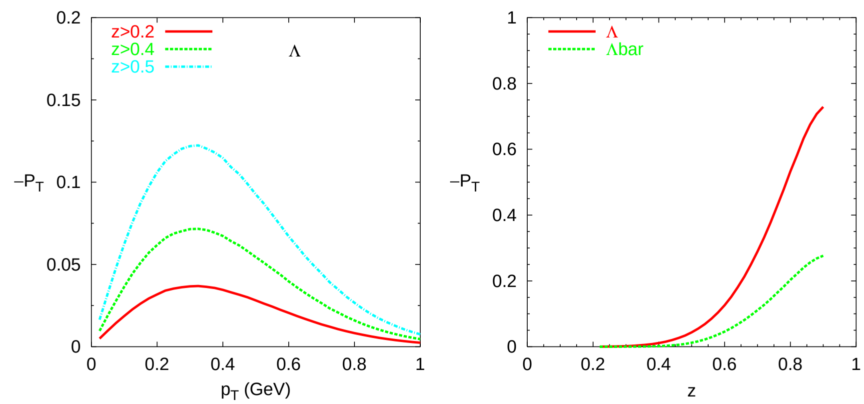

Figure 1: Left: P_T^Λ vs. p_T, averaged over $z > z_0$ for typical HERMES kinematics. Right: $P_T^{\Lambda,\bar{\Lambda}}$ vs. z, averaged over p_T for typical NOMAD kinematics.

where $R = \tan^2\theta_c \simeq 0.056$; notice that at large x and z $P_T^\Lambda \simeq \Delta^N D_{\Lambda^\uparrow/u} \,/\, D_{\Lambda/u}$, and one may have a direct access to the polarizing FF. Analogous expressions hold for the $\bar{\Lambda}$ case, by interchanging D_q with $D_{\bar{q}}$ into (7), (8), and for the $\bar{\nu}$ case by interchanging q, D_q with $\bar{q}$, $D_{\bar{q}}$ into (8).

As an example, we present in Fig. 1 some preliminary predictions for P_T^Λ and $P_T^{\bar{\Lambda}}$ vs. z and p_T for kinematical configurations typical of HERMES and NOMAD experiments. Our results are compatible with present NOMAD data for P_T^Λ in CC interactions;[5] however, only few points with large error bars are available. More precise data, for different kinematical configurations and at larger energies, are required for a detailed test of our model and its predictions, and for more refined parameterizations of the Λ polarizing FF. We hope that these data will be soon available from running or proposed experiments.

References

1. M. Anselmino, D. Boer, U. D'Alesio, F. Murgia, *Phys. Rev.* D **63**, 054029 (2001).
2. M. Anselmino, M. Boglione, F. Murgia, *Phys. Lett.* B **362**, 164 (1995); M. Anselmino, F. Murgia, *Phys. Lett.* B **483**, 74 (2000).
3. P.J. Mulders, R.D. Tangerman, *Nucl. Phys.* B **461**, 197 (1996); B **484**, 538(E) (1997); D. Boer, P.J. Mulders, *Phys. Rev.* D **57**, 5780 (1998).
4. M. Burkardt, R.L. Jaffe, *Phys. Rev. Lett.* **70**, 2537 (1993).
5. NOMAD Collaboration, P. Astier *et al.*, *Nucl. Phys.* B **588**, 3 (2000).